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AN ACOUSTIC COMPARISON OF VOICE USE IN SOLO AND CHOIR SINGING IN UNDERGRADUATE AND GRADUATE STUDENT SINGERS

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by

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Treatise

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Dedication

To my parents,

without whom I could not have dreamed this to be possible.

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Numerous studies have been made looking at the differences in the resonance of choral and solo singing modes. None of these studies, however, have taken into account the particular challenges of a great majority of choral singers: undergraduate and graduate students. An experiment designed to remedy this situation was carried out in which nine baritones and bass-baritones were recording while singing in both solo and choral modes. The singers were divided in to three groups of three singers each, with each group representing a grade-achievement level: undergraduate underclassmen, undergraduate upperclassmen, and graduate students. Singers sang three examples of choral music and two examples of solo music. All the examples were sung in each of four different conditions. The recordings were analyzed in several different ways including spectrogram, formant mapping, long-term average spectrogram, and energy contour. The relative strengths of the fundamental frequency peak and the singer's formant peak were calculated. Results showed that the amount of change in the relative strength of the fundamental frequency between solo and choral modes became greater as the age and experience of the singer increased. Conversely, the amount of change in the relative strength of the singer's formant peak between the two modes dramatically decreased as the age and experience level of the singer increased. The ramifications of these findings on university choral and solo voice programs are discussed.

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Chapter 1: Introduction

The academic requirements placed on undergraduate and graduate singers in vocal performance necessitate the student to learn two different modes of singing. In addition to learning about Western solo classical singing technique, virtually all of the academic institutions granting performance degrees also require their singers to participate in school vocal ensembles. This ensemble requirement most often consists of participation in a choral organization of some kind.

Participation in choirs can be educationally and artistically rewarding. Musicianship and performance skills, ear training, diction, and immersion in diverse musical genres are some of the many benefits a chorister can gain. Choral singing provides the young singer an opportunity to experience a choir's organizational structure, performance practices, and repertoire; these experiences are vital to becoming a choir section leader or conductor. Even if the student intends to become a professional soloist, he can use this knowledge to supplement his earnings as either a concert soloist or as a choir section leader while waiting for his solo career to take hold. He or she may even find an additional avenue of musical expression as a choral conductor, or as a member of a professional choral ensemble such as San Francisco's Chanticleer or Conspirare of Austin, TX.

During their undergraduate and graduate education, singers may encounter substantive disagreements about desirable vocal timbre and voice production between choral directors and voice teachers. One issue that divides them is the proper use—or non-use—of what is termed the "singer's formant." The "singer's formant" (referred to as SF in this paper) is an area of higher acoustical energy situated between 2300 and 3200

Hz in the resonance of a singer's voice.[1] This resonance peak is a central characteristic of Western classically trained solo voices that allows the singer to be heard over an orchestra. These resonance peaks also help to define a singer's individual timbral signature. A primary goal of most voice teachers is to have their students achieve this kind of resonance with minimal effort, allowing them to maintain consistent vocal quality over the course of an entire evening of singing.

By contrast, a primary goal of many choral conductors is to achieve an ideal ensemble sound. The word "blend" is most often used to describe this sound, within which it is very difficult to hear any one singer's individual voice. In order to achieve this blend, the singer is asked to modify his resonance to reduce the amplitude of the SF and match his volume to the volume he hears around him. The use of this technique helps to achieve the "choral effect," wherein the listener's ear perceives multiple sound sources as coming from the same spatial and temporal location. This effect gives rise to the unique sound of a choir—many voices coming together to sound as one.[2]

A pedagogical conflict occurs when a young singer who is learning techniques from his vocal instructor to enhance his SF is simultaneously being discouraged from using those techniques by his choral instructor. This conflict can cause confusion in the

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[1] It is important for me to be clear about the word resonance, as it is a term that is used to mean various things in a variety of contexts. At its most basic, resonance is the process by which small vibrations induce large vibrations, much as an adult pushes a child on a swing lightly but at the correct time in order to cause the child to swing higher and higher. It is the timing of the push that causes the larger and larger swing. If the timing of the push is not in sync with the swing, that push can slow the swing down, or even stop it. When we apply this concept to sound waves, it is the frequency of the sound wave that determines the timing of the "push." When a resonator acts upon a complex sound (or a sound with more than one frequency such as the one coming from the vocal folds), the resonator will amplify certain frequencies, and attenuate (or soften) others. Another way to think of the vocal tract resonance is that of a sound filter, which allows certain frequencies to pass through easily and catches other frequencies. Therefore, whenever I make reference to "resonance", I am referring to this process of the intensification and enrichment of sound that occurs within the vocal tract.

[2] For further information on the choral effect, see (Goodwin, 1980a), (Ternström 1991), and (Eckholm 2000).

young singer, impede his development as a soloist, and potentially hinder his goals as a vocal performance major.

Several studies compare the differing characteristics of singing in choral and solo modes. None of them, however, take into account the specific characteristics of the primary population of choral singers: university undergraduate and graduate students. This paper represents an effort to remedy that situation. By examining the resonance defining characteristics of solo and choral singing in student singers, I hope to illuminate the challenges university voice students face in reconciling the demands placed on their voices. Further, I hope to offer possible solutions to both students and vocal music educators so that voice students may not only navigate these challenges without doing harm to their voices, but also may learn to appreciate and enjoy both methods of singing.

Chapter 2: Literature Review

Differences between Solo and Choral Singing

An early study examining the differences between solo and choral singing can be found in Harper 1967. Its purpose was to determine whether there were differences in vowel formants between speech and classical singing.[3] A group of singers was asked to speak the texts of both choral and solo music pieces, and then to sing those pieces. The vowels [i], [a] and [u] were then isolated and analyzed to find their formant frequencies.[4] The study showed that there were consistent differences in the formant values of sung and spoken vowels. A secondary finding suggested that there was little or no difference between the vowel formants of choral and solo singing. However, there were "timbral" differences between a majority of the vowels in the two singing modes, particularly in [a] and [u]. In other words, when comparing the vowel formants found in solo and choral singing, the first two formants (F1 and F2) did not change. However, F3, F4 and F5 did change, thus changing the timbre of the voice.

Further exploration of this timbral shift can be found in Goodwin 1980a, which specifically examines the differences between solo vocal production and choral vocal production. For this study, thirty randomly selected sopranos sang vowel sounds in a soloistic manner with the subjects hearing themselves first in headphones, and then with a

[3] A formant is a decibel level increase (or peak) of a band of frequencies within the acoustic spectrum of a complex sound. The peak is caused by the enhancement of specific frequencies within the sound by an acoustic filter. In the case of the human voice, the acoustic filter is the vocal tract which modifies its shape (articulation) in order to magnify or diminish partials at selected frequencies to create vowel sounds. Speech requires only the first two formants at the lowest frequencies (F1 and F2). The specific frequencies of these formants define the vowel. In contrast, singing uses from three to six formants. The vowel is made by the first two formants just as in speech, and the timbre or "color" of the voice is determined by formants three and above.

[4] Vowels placed in brackets refer to the corresponding International Phonetic Alphabet symbol. In this case [i] is the vowel in the word "f**ee**d," [a] is the vowel in the word "f**a**ther," and [u] is the vowel in the word "f**oo**d."

pre-recorded tape of other singers singing the same vowels. The singers were instructed to try to blend their voice with what they heard.

The results showed distinct differences between the formant characteristics of the two modes of performance. Blended choral singing showed fewer and weaker partials on frequencies above the first formant; however, partials within the frequency of the first formant were comparatively stronger.[5] Choral singing showed proportionally lower levels of intensity at the second and third formants when compared to the same formants in solo singing. Singers who were singing in the choral mode tended to reduce their overall intensity with respect to the dynamic levels they used in solo singing.

Goodwin theorized that the reduction in the number and strength of partials and reinforcement of the first formant shown in his findings was desirable in choral singing for two reasons. First, Benade (1976) had shown that a tone with more partials will be perceived as louder than a tone with fewer partials. Therefore, reducing the number and strength of the vowel formants is effective for blending because it reduces the voice's perceived loudness and distinguishing characteristics. Secondly, the reinforcement of the fundamental and first formant clarifies both the pitch and vowel—key aspects contributing to the timbre of a choral sound.

The most widely accepted and cited studies on the differences between solo and choral singing are Rossing, Sundberg and Ternström 1986 and 1987. In these two studies, the authors clearly define the primary acoustic differences between the solo and choral modes as found in professional and highly experienced amateur singers. In that, they are the primary inspiration and model for the present study, they therefore warrant an examination in depth.

[5] A partial is a natural overtone of a complex sound. The complex sound is produced by the sound source, which in this case is the larynx itself. Partials are strengthened or weakened depending on the articulation (shape) of the vocal tract (filter), which will create the formants (F1 and F2) of the desired vowel.

For Rossing, Sundberg and Ternström 1986, eight bass-baritones were identified as subjects; three were professional singers, while the remaining five were amateur singers with varying amounts of vocal training and singing experience in both choral and solo settings. Recordings of Poulenc's "Gloria" were made with a binaural microphone placed in the bass section.[6] Copies of these binaural recordings were made at various sound pressure levels ranging from 50-95 dB. Next, a short solo song was composed that incorporated many of the same vowel sounds used in the passages from the Poulenc piece. The piano accompaniment for the song was recorded at high, medium, and low volume levels. The singers were then recorded singing along with the choral and solo recordings playing on headphones. The signal from the recording microphone was added to what the singers were hearing in the headphones by means of a mixing board. Subjects were instructed to sing as though they would typically sing in a choral or solo setting, respectively.

The recordings of the singers were analyzed with a long term average spectrogram (LTAS) for each passage.[7] In addition, the sound pressure levels (SPL) for the singer's formant (SF) region and the fundamental were determined for each passage.[8] Finally, selected pairs of similar vowel sounds sung at the same pitch and SPL levels and the corresponding SPL levels were compared to determine the formant frequencies and the voice source spectrum for each vowel sound.[9]

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[6] A binaural microphone such as the one used for Rossing, Sundberg and Ternström 1986 is designed as a pair of stereo microphones embedded in simulated ear canals of a foam head. The purpose of this type of microphone is to simulate as closely as possible what a pair of human ears would hear, recording not only the sounds themselves but also their location in relationship to the microphone. The binaural recording is most effective when played back through headphones.

[7] A long term average spectrogram (LTAS) is a line graph showing the sound pressure level on the y-axis, and the frequency level on the x-axis. The line on the graph traces the average intensity (sound pressure level) of all frequency bands of a complex sound over the course of the sample.

[8] The sound pressure level (SPL) is a measure of the intensity of a sound. It is measured in decibels (dB).

[9] The voice source spectrum is the spectrogram of the voice source (the vocal folds) before it has gone through the filter (the vocal tract). In the present study it refers to a spectrogram derived by a computer of the sound coming from the vocal folds without the additional resonance added by the vocal tract.

The results of these tests established several important criteria for distinguishing the differences between choral and solo singing. First, when comparing the SPL sung by the singer to the SPL heard through the headphones in a choral mode, the singer would match his level closely to the one that he heard.[10] Conversely, when the singer was in a solo mode, he sang at a consistently higher decibel level than the stimulus recording. Secondly, when comparing the LTAS for each sample, the SF was shown to be strong in solo selections and loud choral singing. By contrast, the choral singing displayed relatively higher intensity levels in the region of the fundamental and F1 than the solo singing.

Finally, pairs of similar vowels from each of the two modes were matched for pitch and sound pressure level. These vowel pairs were inverse filtered by means of a computer program to distinguish between the contributions of the voice source (larynx) and that of the resonator or filter (vocal tract) in the sound spectrum.[11] This comparison showed that the larynx itself contributes more power to the fundamental frequency when singing in the choral mode, and more power to the SF when singing in the solo mode. The results were not always consistent with every singer. The authors concluded, however, that there is evidence that some differences in resonance between solo and choral singing occur at the glottal level as well as through the articulation of the vocal tract. In other words, changes occur not only in the shape and size of the vocal tract between solo and choral singing to increase the energy of the SF or the fundamental, respectively, but changes also occur in the larynx and vocal folds themselves to achieve those same goals.

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[10] The ratio of the decibel level heard by a chorister as compared to the decibel level at which he sings is labeled by Ternström as the Self to Other Ratio (SOR) in (Ternström 1994). This concept will be explored more fully later in the paper.

[11] Inverse filtering is a computerized process by which the effect of the filter is eliminated. What remains is the sound source spectrum.

Rossing, Sundberg and Ternström 1987 is a similar study to the previous one, but it investigates soprano subjects rather than basses and it alters some of the experimental parameters in order to accommodate inherent differences between the two voice types. Five sopranos were recorded while singing in both solo and choral modes; all had considerable voice training. Additionally, two internationally acclaimed sopranos were asked to sing the solo portion under the same conditions. Recordings of the individual singers were made—much in the same way as the previous study—by singing with binaural recordings of choral excerpts of the Poulenc "Gloria." The same passages were then sung in a soloistic manner, and compared. Again, peaks of energy were found in the SF region (defined in this study as between 2 to 4 kHz) most prominently in the internationally acclaimed sopranos. The researchers showed, however, that the frequency of the SF in sopranos is far more variable than it is for all other voice types. This is because sopranos' fundamental frequency is quite high, so that the space between the partials of their fundamental frequency increases dramatically, making it much more difficult to locate the formants of vowels used by sopranos in their upper ranges.

Three subsequent studies on the differences between choral and solo singing have findings that will be helpful to this paper. Ternström and Sundberg (1989) set out to understand how vowels are pronounced differently in choral singing, solo singing, and speech. They also hoped to determine whether singers in a choir alter their vowels to conform to an agreed-upon set of formant frequencies (pronunciation) to achieve choral blend for a particular vowel.

The authors found the vowels of speech to be somewhat neutralized; that is, the formant values of all the vowels drifted toward the values of [ə][12], thereby allowing the speech to flow quickly with minimal effort. The sung vowels were much clearer and

[8]The symbol [ə] is the "schwa" sound, or the sound of an unaccented syllable as in the word "**a**gain."

more distinct than the spoken ones. Further, the formant frequency ranges for F1 and F2 were found to be very similar to each other. This finding suggests that members of the same choir will pronounce vowels similarly in order to achieve blend. Finally, the lower two formants of vowels sung in a solo mode showed little difference to those in sung in choral mode. The most striking differences were found in the fourth and fifth formants, which were lowered in all subjects but one when singing, resulting in those formants being clustered together. The researchers propose, in this study, that formant clustering is the method by which the SF is achieved.

Finally, both Eckholm (2000) and Ford (2000) compare the preferences of various groups for the sound of a choir singing with or without SF resonance. Eckholm recorded a choir of 22 voice students singing four choral pieces in both random and pre-determined standing arrangements and with greater or lesser SF resonance. These recordings were evaluated by a group of choir directors, voice teachers, and non-vocal musicians. Eight members of the choir were also recorded individually, and those recordings were evaluated by voice teachers as well. The results showed that the choir directors preferred the choir's singing when there was less SF resonance, while voice teachers and the non-vocal musicians did not have a preference for either mode. The voice teachers who evaluated the singing of the individual choir members preferred the solo singing mode (with SF resonance) to a blended tone (less SF resonance), saying the blended tone lacked "freedom in production."

The differing expectations for the use of each mode were further explored by Ford 2000. This study assessed the preferences of undergraduate students with varying levels of musical training for choral sound produced with or without strong SF resonance. Recordings of choral selections ranging from Renaissance to late-Romantic styles were made twice—once with a strong SF resonance and once without. These recordings were subsequently played for 139 undergraduate students with vocal musical training, instrumental musical training, or no musical training. Results showed a general preference for the choral singing without a strong SF. This preference was more pronounced in the undergraduates with vocal musical training.

Ford's conclusions for his own study could also apply to the findings of Eckholm when he writes:

> Singing chorally with a less resonant tone quality than fully resonant solo singing may be preferred by auditors, more because of the context of choral singing itself than some universal preference for one correct or even one desirable mode of vocal production… The matter of preference for singer's formant resonance, therefore, need not necessarily be an either/or question. In terms of pedagogy, choir directors and voice teachers, as well as their students, may benefit from seeking greater understanding of how voices can work efficiently and in a healthy manner in a variety of singing contexts (Ford 2000, 45).

The differences between solo and choral singing modes outlined in these studies are summarized in Table 1.

DIFFERENCES IN RESONANCE BETWEEN TRAINED AND UNTRAINED SINGERS

Differences in resonance between classically trained and untrained singers are generally apparent to anyone with a discerning ear. Efforts to quantify this difference appear as early as the second quarter of the twentieth century in Bartholomew 1934. For Bartholomew's paper, recordings were made of 46 males of varying voice quality and training level, which were then were evaluated by a panel of experts to determining the relative quality of each. From these rankings, Bartholomew identified four primary criteria as key components in "good quality" singing: total intensity, a strong low formant, a strong high formant, and vibrato.[13] Of these four, three of Bartholomew's criteria specifically involve resonance, and each will be addressed below.

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[13] Bartholomew's use of the term "good quality" is vague and subjective at best. Given the lack of voice science research in the period of the article's publication, and the pervasive use of terms that are loosely defined at the time, a further definition is required. Taking into consideration the context with which it is

Table 1 – Summary of the Differences between Solo and Choral Singing Modes

	Solo Mode	**Choral Mode**
Fundamental Frequency (F0)	Tends to have relatively *less* energy (dB) that in the timbral formants (F3, F4 and F5). Less energy here is a reflection of the importance of a consistent, full resonance in solo singing.	Tends to have relatively *more* energy (dB) than that in the formants. More energy here allows individual choristers to hear others' fundamental frequency, thereby allowing for easier tuning.
Vowel Formants (F1 & F2)	*Less* energy here than in the upper formants. Clarity of vowel is essential for good enunciation. Because a single singer is not required to match her vowels with other singers, intensity here is less essential. Frequency locations are essentially the same in both modes.	*More* energy here than in the upper formants. This may allow chorus members to match vowel more easily. Frequency locations are essentially the same in both modes.
Timbral or Singer's Formants (F3, F4 and F5)	*More* energy here allows singer to be timbrally distinct from others and to be heard over an orchestra. Clustering of F3, F4 and F5 together allows them to reinforce each other, which creates a SF.	*Less* energy here allows singer to become harder to distinguish from other singers.
Vowel Articulation	Great emphasis on vowel definition and clarity. Modification of vowel only occurs when necessary for a register shift, or for formant tuning in the case of sopranos.	Individuals of a choir will alter standard vowel articulation in order to achieve choral blend. Further, vowels sung by individuals are exaggerated to compensate for the lack of definition in vowel articulation that occurs when many singers are singing together.
Consonant Articulation	Consonants are used to define vowel duration and clarify text. Because the vast majority of vocal resonance occurs on vowels, great care is taken that the consonant is heard but that it not interfere with the flow of the vowel sounds. A term for this quality of vowel-flow is *legato*.	Great emphasis is placed on consonant articulation. Because of consonants' lack of resonant sound, they can be easily lost when competing with other singers singing vowels. Therefore, consonants are often exaggerated, and timed precisely by individual choristers in order that they be heard by the audience.
Self to Other Ratio	Soloist will strongly tend to maintain their energy level above that which they hear, ensuring that they are heard over whatever it is that accompanies them.	Choral singers will tend to match or sing at slightly lower energy levels than that which they hear, allowing their voice to blend with those around them.
Vibrato	Use of vibrato is normal and encouraged in solo singing. It will tend to be slightly wider than choral singing vibrato.	When vibrato is used, it is often a smaller oscillation than that used in solo singing. Some choir directors discourage use of it altogether.
Class Hours	Usually one hour per week is spent	Choral classes meet for multiple

used and its meaning as defined by the bulk of the article, for our purposes we can understand "good quality" singing as "well-trained" singing, and its opposite to be "untrained" singing.

	in the voice studio. That hour may be spent all at one time, or be broken up into two half-hour sessions during the week. Additional hours may be required in the form of a studio-wide masterclass taught weekly, and in preparation for performances.	hours per week, often ranging from three to six each week. As performances approach, additional rehearsals are called. These additional rehearsals can be balanced by "down periods" after the completion of a concert.

Total intensity was listed as a criterion because those whose voices were considered superior were able to produce tone over a large dynamic range. Bartholomew thought that this was brought about by a

> …relatively large throat which is generally necessary to good tone makes possible this increase in intensity by permitting a more vigorous action of the chords, a free egress through the lower pharynx and over the tongue and a greater degree of resonating by tensing of the walls (Bartholomew 1934, 27).

This theory has subsequently been disproved by more recent voice science. As decibel level readings were not a part of the procedure of this study, it is unclear as to whether this dynamic range was due to a change in sound pressure level or a change in the amount and strength of a voice's partials—and thereby the total resonance of the voice.[14] Subsequent studies such as Sundberg 1972b suggest that it may be a combination of the two.

The strong lower formant (approximately 500 Hz) is now understood to be the first singing formant. It is the lower of two formants that determine the vowel being sung. Bartholomew writes that a good-quality voice will have a strong low formant that provides richness and depth of sound to the tone of a singer. By contrast, a lesser-quality voice will not have such strong resonance, or will lack it entirely. Bartholomew observed that many voice teachers advocate vowel alteration in order to lower and reinforce this formant, thereby creating a richer sound.

[14] This difference is explained well in Benade 1976—whereby a tone with more partials is perceived as louder than a tone with fewer partials. Therefore, it is unclear as to whether Bartholomew's distinction was due to a change in sound pressure level or a change in resonance.

The third and primary distinction made in trained voices was the presence of a strong high formant. This high formant was found to be between 2400 and 3200 Hz, and was measured to be present in all male voices. This formant later became known as the "singer's formant." He noted that the frequency range common for this formant happened to correspond to the most sensitive range for human hearing. Further, he pointed out that the frequency of the formant seemed to remain steady no matter what the fundamental frequency was. Because of this, Bartholomew hypothesized that the formant was due to some physiological structure in the larynx that retained its shape and position throughout all frequency variations in the vocal chords and vowel articulations of the vocal tract.

> Since the high formant is determined by the dimensions of the larynx itself, it is not surprising to find its *pitch* at least fairly constant in all voices, good and bad, although its *prominence* usually varies with the excellence of the voice (Bartholomew 1934, 31).

Subsequent to Bartholomew's findings, researchers and pedagogues began exploring the characteristics of the SF. Voice teachers had long known about the development of "ping," or "ring," or "*squillo*" (different names for SF resonance) as a key factor in the development of a singer. William Vennard writes in his classic of vocal pedagogy, *Singing: The Mechanism and Technique*, "I align myself with the pedagogues who believe that 'focus' or 'ping' should be achieved first, last, and always. It is the *sine qua non* of good singing" (Vennard 1950, 88). Limitations in technology hampered these early efforts, however. High-fidelity recordings used for study, high speed digital processing, spectrograms and computers were not commonplace until the 1970s and 1980s. Because researchers were more concerned with understanding the characteristics of the SF itself during the 1950s and 1960s, studies looking at the development of the SF in young singers did not occur until the mid-1970s.

In 1976, Ernest W. Teie wrote his doctoral dissertation on the development of the SF in young singers. The purpose of his study was to determine whether there were differences in the strength of the SF between singers of various training levels and voice types. He found that, overall, the more singing experience a participant had, the more SF they could produce. An additional finding of the study was the lower two formants producing the vowel remained virtually unchanged in all age groups and skill levels, confirming the idea that the bottom two formants determine the vowel, with the upper formants determine the vocal timbre regardless of gender or development level. The findings echo those of Bartholomew, forty-two years earlier.

> The relative intensity of the peak of Fs [SF] appears to be correlated to vocal development. The configuration and breadth of Fs varies little among groups, however, there is a noticeable variation in the relative intensity level among the groups (Teie 1976, 126).

Further corroboration came two years later with a study from Magill and Jacobson, which looked for the existence of the SF in all voice categories and for differences in the strength of the SF between trained professional singers and untrained amateurs. The results of this study indicated the existence of the SF in all voice types, though it was much stronger in lower voice males. Voices in higher voice classifications showed a corresponding rise in the frequency of their SF. Further, the levels of the SF correlated to the experience level of the particular singer; the more experience a singer had, the higher the decibel level of their SF.

Finally, a revealing study Letowski, Zimak and Ciolkosz-Lupinowa (1988) looked at the differences between solo and choral vocal production by the same singer. The findings of this study followed the same pattern outlined earlier in this paper: the SF was more prominent in solo singing than a choral setting. Even more striking, however, were its findings showing trends of experienced and inexperienced singers in choral and solo settings. The study reported that,

> vocally untrained singers tend to operate with a richer (brighter) voice while singing in an ensemble than in solo mode, and… [that] voices of vocally trained persons sound richer (more powerful) in solo singing than in choral performances where the singer's formant is frequently totally missing, but nevertheless the presence of such voices on the ensemble is often an essential factor mobilizing the other performers (Letowski, Zimak and Ciolkosz-Lupinowa 1988, 65).

In other words, untrained singers sing more resonantly when they are singing in a group and trained singers sing more resonantly when they are singing as a soloist.

Based on the studies outlined so far, we can come to some preliminary conclusions about the role of the SF in the developing singer. These conclusions can also serve as points of departure for questions to be addressed later in this paper. First, a primary difference between choral and solo singing is the strength of the SF, which is also creates the primary resonance difference between trained and untrained singers. This fact gives rise to the question "What are the effects of vocal training on the relative levels of SF in choral and solo singing?"

Secondly, choral singing tends to have more energy in the fundamental frequency and vowel-shaping formants (F1 and F2), which is where inexperienced singers will naturally feature more resonance. This leads us to ask "Are inexperienced singers naturally predisposed to choral singing, and as they are trained move away from singing patterns that are beneficial to choral blend?"

Finally, an inexperienced singer will sing more fully within a group of singers than will a trained singer. Is this because they have other singers singing their part along with them, or are there other factors that allow or encourage an inexperienced singer to sing with more sound pressure and/or resonance in a group than they would sing by themselves?

An Understanding of the Singer's Formant

In order to understand the relationships between solo and choral singing modes and the differences between trained and untrained singers, it is important that we understand what the singer's formant is, how it is formed, and how it is used in solo Western classical singing. After the publication of Bartholomew's article (1934) on the characteristics of good singing, much of the voice research for the next several decades centered on the differences between spoken and sung vowels. These articles confirmed Bartholomew's findings by noting the existence of the SF peak as a primary timbral characteristic of solo singing. However, since the focus of these articles did not specifically center on the SF, little but the acknowledgement of its existence was confirmed. One such article (Rzhevkin 1956) used oscillographs, a precursor to the modern spectrogram, to measure resonance characteristics. An important contribution of this study is that the frequency of the SF corresponds to the frequencies to which the human ear is most sensitive. This fact becomes critical when we explore how the SF is used by singers in performance. Vennard and Irwin (1966) also looked at the differences between spoken and sung vowel characteristics. Their findings include the fact that sung examples were regularly about 10dB louder than the spoken examples. Further, sung examples displayed more intense formants in relation to the more diffuse profiles of the spoken examples. These findings regarding the intensification of formants were vital in forming a subsequent understanding of how the SF is formed by the singer.

The researcher who has contributed most to our understanding of the SF is Johan Sundberg, Professor of Music Acoustics at the Royal Institute of Technology in Stockholm, Sweden. His interest and perseverance, along with leaps in computer and audio technology at this time made these breakthroughs possible. In a series of studies carried out during the 1970s, Sundberg greatly improved our understanding of the phenomena surrounding the SF. The purpose of his first exploration (Sundberg 1970a) was to determine the differences between spoken and sung vowels by way of studying their respective formant frequencies, in much the same way as his predecessors had done. This study ascertained to what extent differences in the formant frequencies are caused by articulatory changes (changes in the vocal tract) and/or source (glottal) differences. Sundberg showed the specific frequencies for the first and second formants of nine vowels, and linked the control of the frequencies of those formants to particular articulators in the vocal tract. For example, control of the frequency of the first formant is due in large part to the position of the jaw—the more open the jaw, the higher the first formant will become. Of primary importance are Sundberg's theories as to the nature of the SF and its source: the SF is not a single formant, but rather a clustering of the third, fourth and fifth formants into the range of approximately 2.5 to 4 kHz which appear as one single peak on LTAS analyses.[15] This formant clustering is thought to be achieved through articulatory processes which are the result of vocal training.

Sundberg (1970b) goes on to test his hypotheses about the SF. He attempted to predict the intensity level of the SF based on the intensity of the fundamental frequency, the source spectrum, and the formant frequencies of the given vowel. Also, Sundberg hoped to find a correlation between the level of the SF and source spectrum in various voice classifications.

Sundberg found that he could predict the intensity levels of the SF based on the controlling factors listed above. This ability to predict the levels of the SF led him to conclude that the SF is formed by a clustering of the third, fourth and fifth formants. He

[15] A long term average spectrogram (LTAS) is a line graph showing the sound pressure level on the y-axis, and the frequency level on the x-axis. The line on the graph traces the average intensity (sound pressure level) of all frequency bands of a complex sound over the course of the sample.

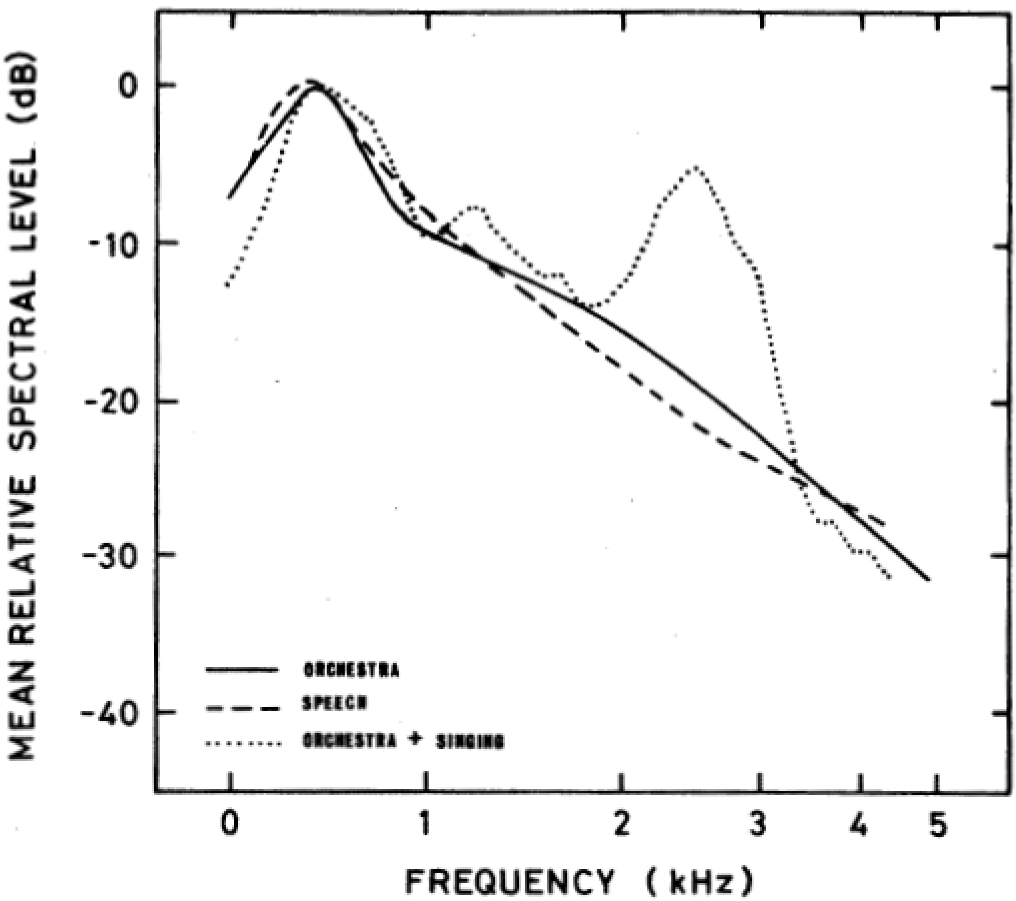
argued that this cluster of formants is generated by articulators that increase the space within the sinus piriformis and sinus Morgangni, two sets of cavities that lie between the larynx and the pharynx.[16] Sundberg also found considerable variation in the intensity of the SF in relation to that of the fundamental frequency, and showed that these variations are heard in the timbral color of the singer. "Lighter" voices have a comparatively greater intensity at the SF frequencies in relation to the intensity of the fundamental frequency than "darker" voices. Furthermore, the darker voice produces a higher total SPL value;[17] however, the relative intensity of its SF will be less than that of the light voice. Conversely, the light voice does not produce as much overall SPL, although the relative SF is higher. Because of this, the actual SF value of both singers is comparable.

Sundberg then turned his attention to reasons why the SF is so vital to the success of the classically trained singer. To that end, he constructed LTAS charts for several recordings of orchestral works of various musical styles from Mozart to Wagner. These spectrum charts had curves showing an intensity peak at approximately 450 Hz, followed by a declining slope of about 9dB per octave. This decline is due to the natural phenomenon of exponential decay in the decibel level of partials at higher and higher frequencies. Coincidently, the curve shown for the orchestra is very similar to the LTAS of a speaking voice, peaking and decaying in a similar fashion. With this profile, a human voice could not possibly be heard over an orchestra playing at an overall SPL of 90dB, a level common to the loud passages of late-Romantic and twentieth century pieces. Even a Shakespearian actor orating at the top of his lungs would be able to produce a total of only 80 to 85 dB at the very most. However, because of the natural exponential decay of partials, the SPL of the orchestra is reduced by about 25 decibels at

[16] In a later article (1972a), Sundberg confirmed the SF consists of the clustering of the third, fourth and fifth formants and that the sinuses piriformes and Morgangi are the sources of those formants.
[17] Sound Pressure Level, measured in decibels (dB).

the frequency of the SF (approximately 3 kHz); whereas that of a singer with SF will drop only about 8 decibels at that frequency. Therefore, if our singer were to sing at an overall level of 75dB, his intensity would be sufficient to be heard over the orchestra playing at 90dB.

Figure 1 – LTAS of Speech, Orchestra, and Orchestra with Tenor (Sundberg 1972b, 62)



The effect of the SF can be seen most clearly in Figure 1 taken from Sundberg 1972b (62). In this graph we see three separate LTAS curves. The solid line represents the curve of an orchestra by itself, the dashed line shows the curve of a speaking voice, and the dotted line shows the curve of tenor Jussi Björling singing with an orchestra. We can plainly see how Bjorling uses the resonance in his SF to create more sound at frequencies in which the orchestra does not have very much power. Bjorling is heard not necessarily at the level of his fundamental frequency, but rather through the reinforcement of his overtones or partials.

Sundberg (2001) further defined what is meant by the singer's formant, and how it contributes to the overall vocal timbre and the classification of a particular voice. Again, he was able to confirm that the SF is a cluster of formants 3, 4 and 5, which is present in all voice types other than soprano. This time, however, he was able to calculate that the SPL of the SF increased an average of 1.6 to 1.9 dB for every one decibel increase in the fundamental frequency. Further, Sundberg demonstrated that the mean frequency of the SF was a primary indicator of the singer's voice type; the higher the frequency, the higher the voice type. For example, altos' average SF frequency is approximately 3 kHz, whereas basses have an average of 2.42 kHz.

Through the work of voice scientists such as Sundberg, we can observe the fundamental importance of the SF to the solo classical singer, not only as a method of enriching the singer's vocal timbre, but also as the primary method of projecting over an orchestra. Further, we can understand that the development of the SF in a voice is the result of training over a number of years, and is a key indicator of the overall technical development of a singer. Finally, we can observe that the overall success of a singer attempting to negotiate the demands of both solo and ensemble singing hinges on his or her ability not only to produce the SF, but to control its intensity in relation to the strength of the fundamental frequency and lower formants. This paper hopes to identify one of the primary challenges facing student singers of varying skill levels in negotiating the diverse demands of solo and choral singing: the use of the singer's formant. In so doing, I intend to provide a basis upon which dialogue between voice teachers and choral directors can be established, in order that the students they jointly teach will be able to perform in both modes in a healthier and musically more successful manner.

Chapter 3: Methods and Procedures

STIMULUS RECORDING

In preparation for this study, I recorded a choir of approximately forty members in a performance of the "Hallelujah Chorus" from Händel's *Messiah*. The recording was made in the choir's regular rehearsal room. For this recording, the goal was to recreate as closely as possible the sensation of being inside the choir, and I therefore decided to use a binaural recording technique. Binaural recording is a method of recording audio that uses a special microphone arrangement that simulates the ear canals of a human head. The result is a recording that accurately reproduces the 360° effect of hearing a sound in space. Binaural recordings can convincingly reproduce the relative locations of wherever the sound actually originates during recording. Though I was not able to secure a true binaural microphone, I was able to simulate a binaural microphone by using a pair of directional microphones (AKG model C451B/ST) placed on either side of a solid metal music stand and positioned within the bass section of the choir. This simulation would allow the test subjects more accurately to recreate their choral mode of singing as they attempt to blend with what they hear. The signal for the choral recording was then fed into a preamp (model ART Digital MPA) and recorded by a compact disc recorder (Marantz model CDR510/U1B). The recording of the rehearsal was edited to extract three different passages from the piece containing a wide range of pitches, vowels and dynamic levels. The passages include measures 1-11 (example 1), 33-41 (example 2), and 74-81 (example 3).

As further preparation, I recorded the accompaniment for "The Star-Spangled Banner" using the same recording apparatus as with the choral recording. This time, however, it was not necessary to record using a binaural method, since the sound of a piano accompaniment arises primarily from one location rather than all around as in a choir. I also edited the recording to create two selections, measures 1-8 (example 5) and 24-32 (example 5).

PARTICIPANTS

Nine student baritones and bass-baritones were asked to participate in this study in which they were recorded singing in both choral and solo modes. I chose them based on their high experience level in both solo and choral singing. I also made sure that the population of participants had an equal distribution of grade-achievement levels, and had sufficient numbers of students in each level capable of providing a sufficient sample for each group.

The nine participants were divided into three groups of three based on their grade-achievement level. “Group 1” consisted of underclassmen, or first and second-year undergraduate students. “Group 2” were upperclassmen, or third-, fourth-, and fifth-year undergraduate students. Finally, “Group 3” consisted of both masters and doctoral students. For purposes of the study, each participant was referred to by a three-digit number. The first of the numbers refers to the participant’s group. The remaining two reflect the chronological order in which the testing took place. For example, the second subject tested in Group 2 is numbered 202. Each participant completed a survey inquiring about their levels of experience in both choral and solo singing, and their personal preferences about performing in both modes. Average age levels and levels of experience are shown in Table 2. The remaining results of the survey will be discussed later in the paper.

Table 2 – Average Age and Levels of Experience of Participants[18]

	Average Years of Age	Average Years of Choral Experience	Average Years of Solo Voice Lessons
Group 1	18.67	9.67	4.67
Group 2	22.67	11.33	6.00
Group 3	30.33	9.33	8.00

SAMPLE RECORDING

Once the survey was complete, the participants recorded in a voice laboratory. Each subject sang three passages from *Messiah* and the two passages from *The Star-Spangled Banner* four separate times under differing conditions. For these recordings, the subjects sang into a Shure SM81-LC microphone, which sent its signal through a 20 dB attenuator pad and then into a Kay Elemetrics 4300B digital interface where the signal is digitized. The digital signal then went into a Dell MMP microcomputer running the application Multispeech published by KayPentax, which recorded and stored the sample for subsequent analysis. For the duration of each recording the participant was placed exactly six inches away from the microphone in order to obtain accurate and consistent SPL measurements. Table 3 shows the procedure followed for each recording session.

Table 3 – Outline of Recording Procedure

I. Subject records audio samples
   A. Subject records choral examples
      1. Choral example 1, "Hallelujah Chorus" measures 1-11
         a. *a capella*
         b. *a capella* with headphones
         c. with headphones at low volume
         d. with headphones at high volume
      2. Choral example 2, "Hallelujah Chorus" measures 33-41
         a. *a capella*
         b. *a capella* with headphones
         c. with headphones at low volume
         d. with headphones at high volume

[18] As the average age levels and overall experience levels increase with each group number (except as shown), the terms "age level" and "grade-achievement level" will be used interchangeably for the purposes of this study.

3. Choral example 3, “Hallelujah Chorus” measures 74-81
    a. *a capella*
    b. *a capella* with headphones
    c. with headphones at low volume
    d. with headphones at high volume

B. Subject records solo examples
    1. Solo example A, “The Star-Spangled Banner” measures 1-8
        a. *a capella*
        b. *a capella* with headphones
        c. with headphones at low volume
        d. with headphones at high volume
    2. Solo example B, “The Star-Spangled Banner” measures 24-32
        a. *a capella*
        b. *a capella* with headphones
        c. with headphones at low volume
        d. with headphones at high volume

As shown in the outline, the subject sang the passage *a capella* on the first trial. This step was taken done to set up a base line control recording of the singer’s voice without outside influence. Next, the subject sang the same passage *a capella* with a set of stereo headphones over their ears. These headphones (Sony brand MDR 7506) would be used to play back the choral and accompaniment stimulus recordings. It was important to set up this second base line, since the headphones were required for recording samples “c” and “d” in each example.

The headphones contribute another factor that must be taken into account, since they affect how the singer hears himself. By covering the singer’s ears, he is not able to hear as much of his own voice coming back to him off the walls of the room. When a singer is not hearing enough of his own sound due either to outside noise or to limitation in his hearing, he will increase his volume in order to hear himself sufficiently. This phenomenon is called the Lombard vocal response.[19] Ternström (1999) looked at this phenomenon specifically in relation to singing in a choral environment. Because a singer

[19] For further information about the Lombard vocal response and its effect on choir singers see Tonkinson 1990, and Ternström 1999.

must hear both himself and the choir around him, Ternström measured this ratio using microphones both in the singer's ears and in front of his mouth. He calls this measurement the Self-to-Other Ratio (SOR). According to Ternström, each singer will have a fairly limited preferred SOR range. The individual's preferred SOR depends upon many factors, ranging from the singer's voice type to their normal position in a choir to the acoustics of the room itself. Each of the singers in this study naturally has his own particular SOR. Therefore, it was necessary to calibrate the singer's performance to a second base-line using headphones in order to account for their reduced ability to hear themselves, and consequently for their preferred SOR.

Finally, the subjects sang the examples along with the choir recording. They were asked specifically to sing as though they were in the choir and to use techniques for quality choral singing. They were not, however, asked to "blend" their sound with what they heard. The participants sang with the recording twice at two different volume levels. In the first trial, the decibel range of the recorded choir was 52 – 83 db; and in the second trial the volume was increased so that the decibel range was 57 – 88 db. This is completely in the range of normal according to the chart given for average decibel levels in Everest 2001 (28-29).

A second set of recordings was made using the same procedure (as shown in Chart 1) with the singer employing the solo mode. Participants were instructed to sing the excerpts as though they were singing them in a concert recital, and to use their best soloistic voice.[20]

[20] Subsequent to the voice recording, a Voice Range Profile (VRP) was then created for each singer. A VRP, also known as a phonetogram, is a graphic representation of the potential dynamic range of a voice on each discrete pitch the voice is able to sing. VRPs are used in voice therapy as a diagnostic tool and for tracking progress in patients. Recently, applications for using VRP have been developed to help singers with issues such as voice classification and balance of vocal registers. It was my hope to use the VRP as a way to measure the potential sound output of each participant's voice, and then compare them to the average and maximum outputs in each example. Unfortunately, due to limitations of the equipment employed, the data collected was unusable without serious concerns as to its integrity. I therefore decided

Once all the recordings were made, I analyzed them in several different ways. Using the Kay program, I created a spectrogram, formant history, energy contour, and long term average spectrum (LTAS) for each trial. From those analyses I developed statistics for average frequencies and energy (dB) levels for the formants. Those averages were then used to develop a data set that included average decibel levels for each sample at 200 Hz (approximately the fundamental for our singers), 500 Hz (approximately the first formant), and the highest peak above 2000 Hz which is the level used for the Singer's Formant.

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to discard this part of the experiment, and concentrated my efforts on the recorded examples. For further information on how phonetograms are used to help singers, see Titze 1992, Sulter et al. 1994, and Mürbe et al. 1996.

Chapter 4: Results

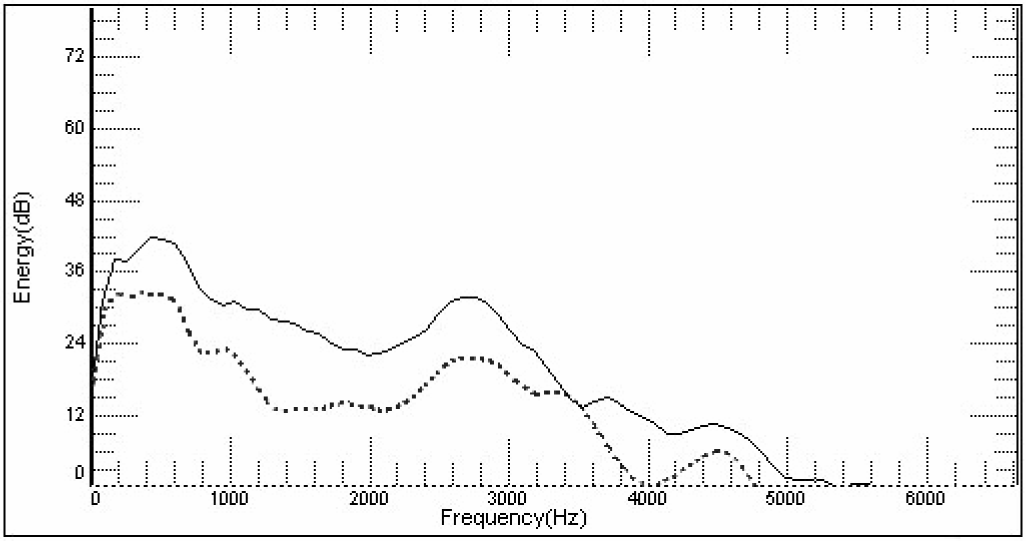
DIFFERENCES BETWEEN SOLO AND CHORAL MODE

Figure 2 shows a typical Long Term Average Spectrogram (LTAS) of the two modes of singing. On these graphs, the y-axis indicates the amount of energy, and the x-axis indicates the frequency in the sound spectrum measured in hertz (or cycles per second). The line indicates the average amount of energy (dB) in each frequency band over the course of the recorded example. This particular example is from participant 202, showing solo example 5 (solid line) and choral example 2 (dotted line), each with loud accompaniment. The formant peaks are at approximately 500 Hz (first formant), 1000 Hz (second formant), 2800 Hz (third formant), 3400-3600 Hz (fourth formant), and 4500 Hz (fifth formant).

The apparent differences between solo and choral mode seem at first glance to contradict the Rossing, Sundberg, and Ternström study, which showed choral singing to have stronger fundamental and first and second formants (between 0 and 1000 Hz) than solo singing. In line with this example, a significant majority of the subjects' solo singing was stronger overall at every formant peak. However, figure 2 must be understood in the context of what the singers were hearing as they sang. Rossing, Sundberg, and Ternström found that the decibel level of the stimulus recording directly affects the both overall decibel level at which the singers will sing, and by extension the decibel level of the formant peaks. They noted

> …that in the choral mode, the subject generally adjusted his singing level to the other singers, whereas in the solo mode the level of the singing often differed considerably from that of the piano accompaniment (Rossing, Sundberg and Ternström 1986, 1976).

Figure 2 – Sample LTAS of Choral and Solo Singing



Participant 202, choral example 2 (dotted) and solo example 5 (solid) (LTAS graph)

To investigate this issue further, I determined the decibel level of the stimulus recording at the singers' ears by measuring the amount of voltage coming out of the mixer into the headphones and calculated the decibel level using the manufacturer's specifications for the headphones' sensitivity. The purpose for doing this conversion is twofold: it ensures that the stimulus recording is sounding within normal decibel level parameters of the sounds it is attempting to simulate. Further, this conversion enables comparisons to be made between the level being heard by the singer and the level being sung by the singer. Table 4 shows the range of levels heard by the singers and the average peak dB levels the singers sang.

Note that each of the groups kept their singing decibel level within the same range as that which they were hearing in the choral examples (1, 2 and 3). Conversely, the singers kept their level above the average of what they were hearing in the solo examples (4 and 5). This is quite consistent with the findings of Rossing, Sundberg, and Ternström. It is also interesting to note that several of the average peak levels for the soft trials have a higher decibel reading than the loud trial for the same example. This definitely suggests that, though the stimulus recording is a major factor, there is much more to overall decibel level in both choral and solo singing then the level of the surrounding singers or accompaniment.

Table 4 – Comparison of dB Level of Stimulus Recording and Average Peak dB Level Sung by Group

	dB range heard by singer in stimulus		Average peak dB level sung Group 1		Group 2		Group 3	
	loud	soft	loud	soft	loud	soft	loud	soft
Example 1	57 – 86	52 – 81	95.08	85.15	97.82	95.57	98.42	97.71
Example 2	58 – 84	54 – 79	87.25	87.55	99.44	92.35	105.11	107.49
Example 3	60 - 88	55 – 83	93.46	93.73	102.57	99.72	102.86	105.06
Example A	66 – 92	61- 86	106.43	96.64	104.93	104.25	104.97	108.79
Example B	67 – 90	62 - 84	98.68	99.82	104.29	103.24	108.27	106.66

Though figure 2 shows significantly different formant peak levels in the representative LTAS from those expected based on Rossing, Sundberg, and Ternström, a more significant similarity lies in the relationship of the peaks to one other. One way to look at these relationships is to determine their relative strength. This number is calculated by finding the difference between the level of the largest peak (most often that of the first formant) and that of any other peak in the spectrogram. The formula is $[F_1 - F_x]$; where F_1 is the SPL of the first formant, and F_x is the strength of the formant in question. As the amount of strength in F_x rises, the lower the numerical result for the equation will be. Therefore, the numerical value given for the relative strength of a formant peak is inversely proportional to the strength of the peak in question. In other words, the lower the given number as the relative strength of a given peak, the greater the relative strength of the peak.

Rossing, Sundberg, and Ternström found that in solo mode the relative strength of the fundamental would be low, and the relative strength of the SF would be high. This is because the singer is attempting to use his SF resonance to cut through the orchestra. It is less important for him to emphasize the fundamental, because it will naturally get enough vocal energy. Conversely, in the choral mode the relative strength of the fundamental would be higher, and relative strength of the SF would be lower. This is because the pitch of the fundamental is essential maintain proper tuning, and because the SF resonance must be attenuated so that the individual does not stand out of the group. This relationship between the dB levels of the formant peaks is essential to understanding the differences in resonance between the solo and choral modes.

Table 5 provides an example of this relationship using the levels of the examples from figure 2. The decibel levels of the 200 and 500 Hz frequency bands given in table 5 represent the decibel levels of the fundamental and the first formant, respectively. The level of the SF is taken at the highest peak between 2500 and 3500 Hz. Using those levels, table 5 lists the relative strength of the fundamental peak and the SF peak.

Table 5 – Relative Strength of Fundamental and Singer's Formants in Choral and Solo Modes as Shown in Participant 202, Examples 2 and 5

Formants (dB)	L_{200} (f_0)	L_{500} (f_1)	*Relative Strength of* L_{200} $(L_{500} - L_{200})$	L_{500} (f_1)	L_{sf} *(singer's formant)*	*Relative Strength of* L_{sf} $(L_{500} - L_{sf})$
Choral (Example 2)	30.90	31.11	0.21	24.59	14.40	10.19
Solo (Example B)	23.27	24.59	1.32	31.11	22.14	8.97

The statistics in table 5 show that the relative strength of the fundamental is low in solo mode, and in choral mode the fundamental is relatively stronger. Conversely, in solo mode the relative strength of the SF is high, and in choral mode the SF is relatively weaker. By measuring these relationships, one is able to measure to what degree a singer is changing his vocal resonance to create a singing mode. Further, that measurement is independent of the amount of total decibels the singer is producing. The relative strengths of the frequency bands determine the mode.

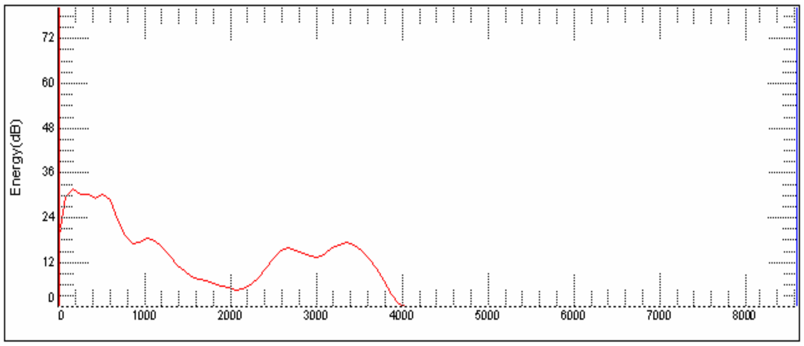
DIFFERENCES BETWEEN GRADE-ACHIEVEMENT LEVELS

Figure 3 shows three sample LTAS graphs of singers from the three different grade-achievement level groups singing the same musical example under the same conditions. For these figures example 2 from the "Hallelujah Chorus" was used, sung with accompaniment at the louder setting. They show typical examples of LTAS graphs for baritone and bass-baritone classical singers. The first peak is located around 200 Hz, understood to be the range of the fundamental frequency for this voice type. Often there is a small peak in the 500 Hz range, indicating the range of the vowel-shaping first and second formants. Finally, note the large second peak between 2800 and 3200 Hz, representing the SF.

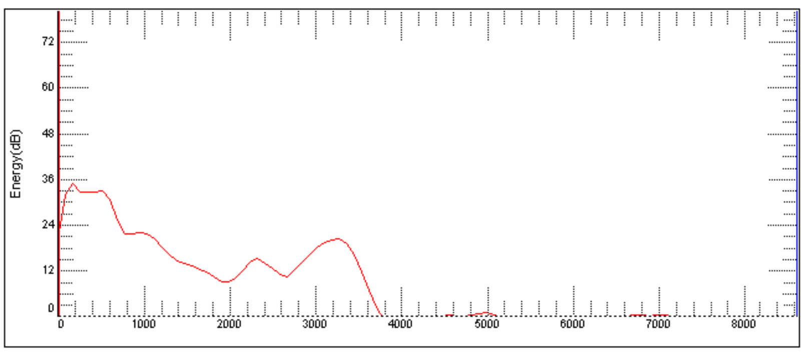
Upon further examination of these graphs, the difference between the three age categories becomes clear. The younger singer has all the typical peaks that are expected of a trained classical singer. Further, he has already begun to create a SF around 3000 Hz. However, at this stage in his development he has not learned how to cluster the fourth and fifth formants close together, as indicated by the double peak. The singer in the second group makes a bit more sound than the first group singer, but he, too, has not learned to cluster the fourth and fifth formants sufficiently. Only the graduate student singer, on the verge of entering the professional world, is able to combine power with a fully developed resonance. It is important to note that the younger singer should not be expected to have as much resonance as the other singers because of his age and training level. Only with consistent practice over an extended period of time can a young student develop the vocal command of the graduate student. More importantly, the ability to

Figure 3 – Sample LTAS Graphs of Three Grade-Achievement Levels

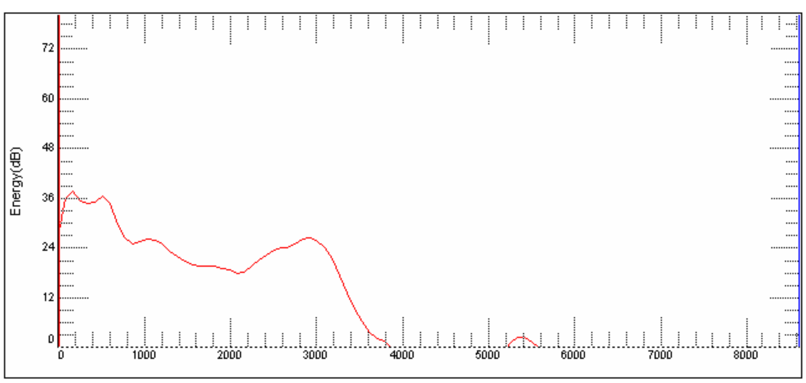
Participant 101, Example 2 – loud (LTAS graph)



Participant 203, Example 2 – loud (LTAS graph)



Participant 302, Example 2 – loud (LTAS graph)



produce a consistent SF at all times is a matter of proper vocal technique, not physical power. Proper vocal technique is also the product of study over time, and students and teachers should never be in a hurry to produce large amounts of sound.

Figure 4 includes three spectrogram graphs with formant mapping added in red. Each graph acts as a representative of its group (i.e. underclassmen, upperclassmen, or graduate). Again, I have used the same musical example sung in the same manner for each of the graphs. In this case it is the opening line from *The Star-Spangled Banner*, known in this study as example 4. The spectrogram shows the intensity of the formants over the length of the example. The x-axis represents time, and can easily be followed with the song's text printed underneath. The y-axis is used for frequency, while intensity is indicated by the shades of gray within the graph. The darker the shade shown, the more intense (more decibels) the sound is at that frequency. The red dots indicate points in the graph that the computer has calculated to be part of the subject's SF. Seen as a whole, the dots trace out the SF over the course of the excerpt. In general, we are looking for a strong and consistent line of dots to trace the SF over the entire graph, maintaining its intensity and frequency.

When we compare the three examples, the trends suggested in figure 3 are reinforced. The example from Group 1 (underclassmen) is a noticeably lighter shade of gray than the other two, indicating a lower amount of overall resonance. The SF as mapped out by the computer is likewise weak and inconsistent. The frequency of the formant consistently starts high at the onset of a syllable, and dips lower at the end. One can hear the inconsistency in the sound when listening to the musical recording. In the example from Group 2, one can immediately see an increase in the amount of power in this singer as indicated by the darker shades of gray. However, his SF tracking is even less consistent than the singer in Group 1. When reviewing the recording of this

Figure 4a – Spectrogram and Formant Map, Participant 101 Example 4

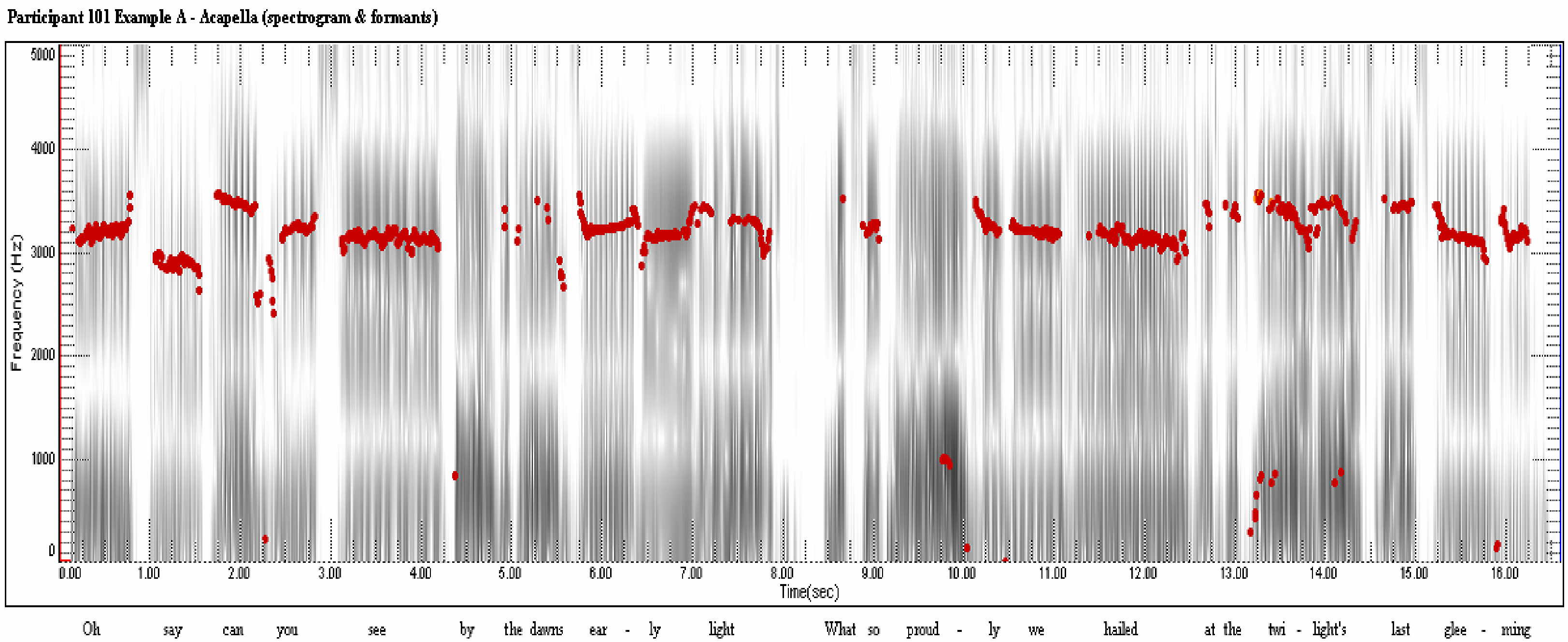


Figure 4b – Spectrogram and Formant Map, Participant 201 Example 4

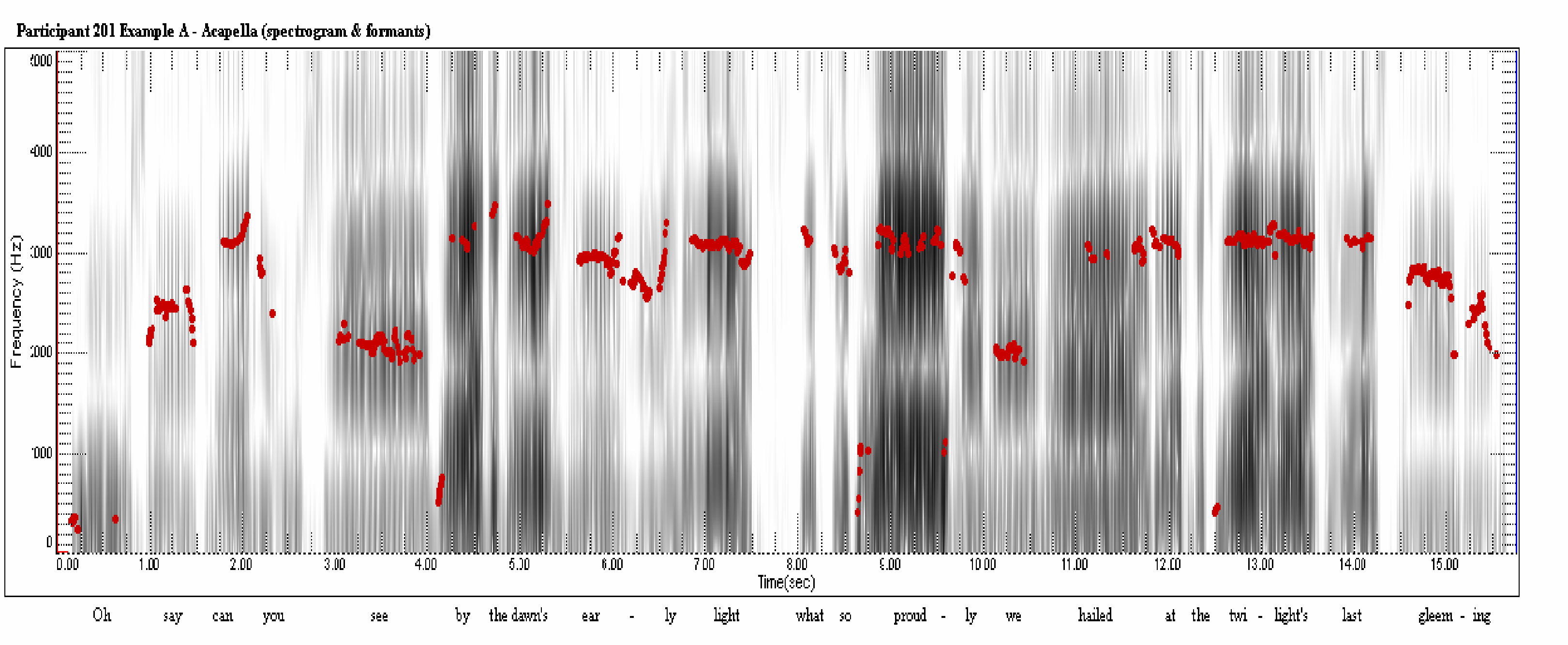
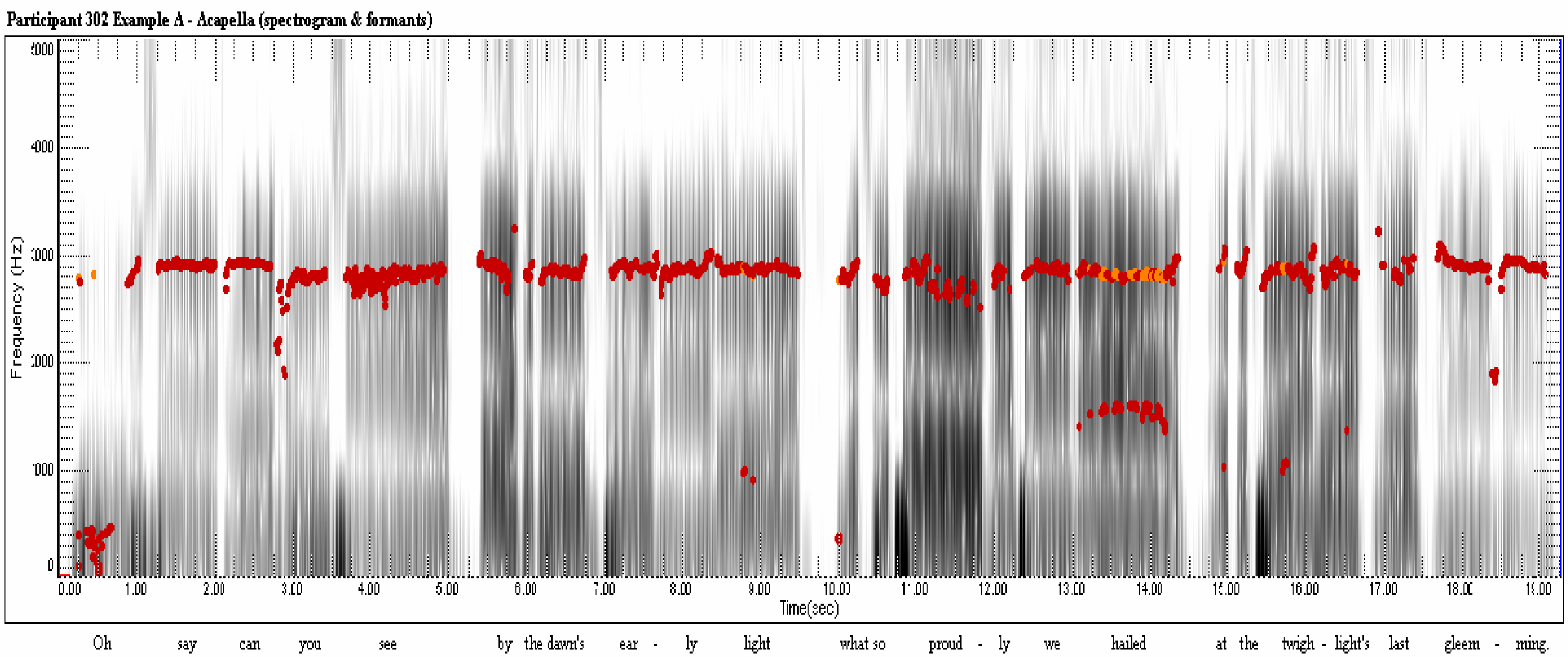


Figure 4c – Spectrogram and Formant Map, Participant 302 Example 4



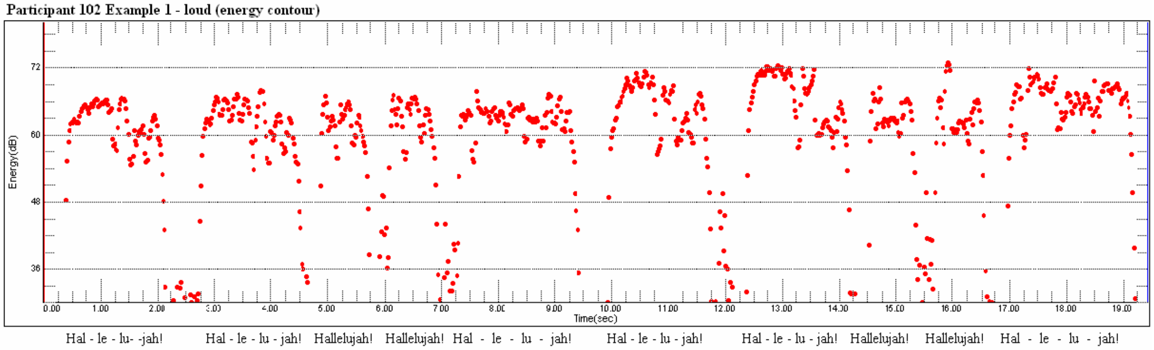
example, the listener was left with the impression of considerable power without much control or vocal beauty. The final example shows the combination of both strong resonance and an extremely consistent SF. It is impressive, that even in the short notes, the SF is always prominent and always at the same frequency. This singer has learned to produce SF on all sung pitches regardless of the phoneme presented.

Figure 5 represents sample energy contours taken from each of the three groups. These graphs are similar to the spectrograms, in that they are designed to show intensity over time. Again, the x-axis represents time and is accompanied by the words so that the reader may follow the contours easily. The y-axis shows the intensity, or decibel level, of the sample. The contours are derived in the same manner as the formant mapping: the computer creates it by plotting many individual points on the graph.

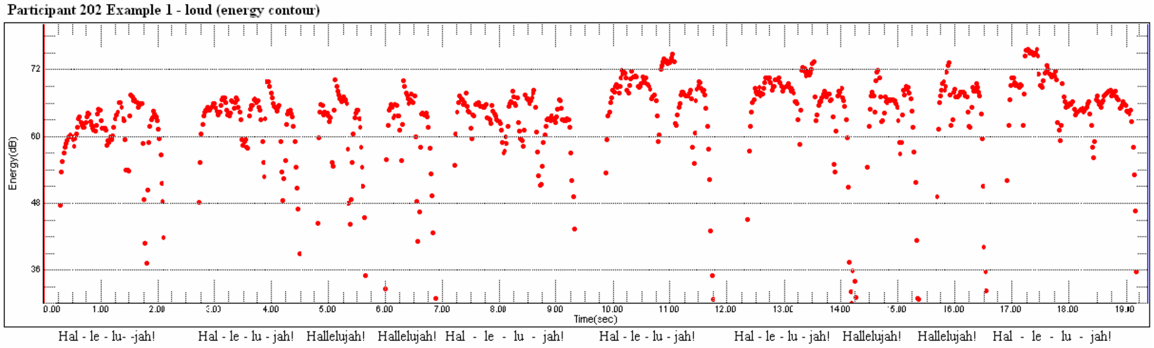
As previously discussed with respect to the LTAS and the spectrogram graphs, the more experience the singer has, the more power he displays. Further, the more experienced singer shows greater consistency. The graph for the singer in the Group 1 shows that it takes a certain amount of time for him to achieve the desired dynamic level. This can be partially attributed to the initial consonant [h] used repeatedly in this example. However, one can see that the singer in Group 2 takes less time to achieve his dynamic level for the same task; and the singer in Group 3 still less. These graphs suggest another factor that separates less-experienced singers from professionals. An experienced singer is able to initiate the tone at the dynamic level he wants through the use of a balanced onset and a vocal tract already featuring its correct articulation for maximum resonance of the given vowel. A less-experienced singer will have to “fish” for a split second before he finds what he wants. This adjustment takes away energy that could otherwise be used for producing more resonance and ultimately results in an inconsistent or hesitant tone that requires more vocal energy.

Figure 5 – Sample Energy Contour Graphs of Three Grade-Achievement Levels

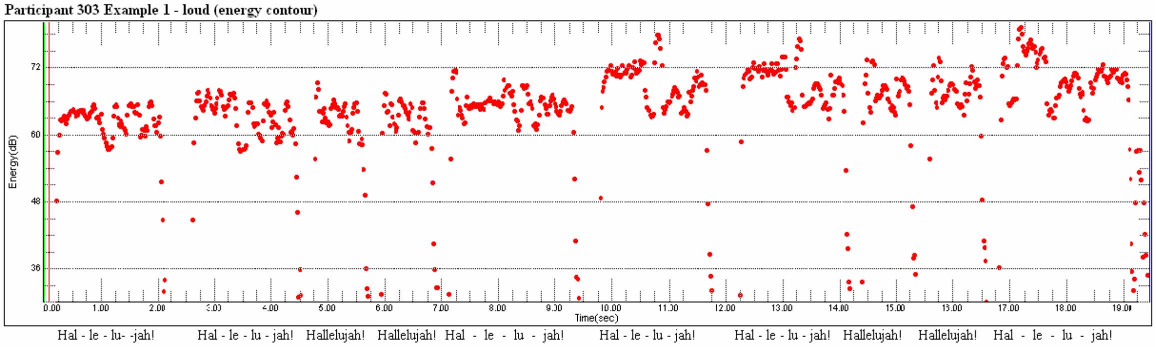
Participant 102 Example 1 - loud (energy contour)



Participant 202 Example 1 - loud (energy contour)



Participant 303 Example 1 - loud (energy contour)



THE EFFECT OF GRADE-ACHIEVEMENT LEVEL ON THE DIFFERENCES BETWEEN SOLO AND CHORAL SINGING

In order better to understand what effect grade-achievement level has on the resonance characteristics of the solo and choral singing modes, I took measurements of the decibel levels from each example for each participant at the fundamental frequency (200 Hz), the frequency of the first formant (500 Hz), and at the highest peak between 2500 and 3500 Hz at the level of the SF. I then averaged the levels for the choral examples of each Group together, and did the same for the solo examples. The following chart shows the results.

Table 6 – Average dB Values of Formant Peaks

Participant	*Choral Averages*			*Solo Averages*		
	L_{200}	L_{500}	L_{sf}	L_{200}	L_{500}	L_{sf}
101	22.56	19.68	6.59	21.65	18.39	14.40
102	24.73	25.11	7.00	23.75	23.42	8.15
103	21.39	18.42	3.09	22.02	19.11	5.01
201	24.82	26.92	13.77	25.68	26.62	17.39
202	29.07	29.97	19.12	27.23	28.32	17.35
203	25.86	25.01	13.87	24.22	22.53	11.80
301	22.62	23.34	14.46	23.11	23.33	15.65
302	25.44	25.11	16.49	24.67	22.96	14.51
303	25.72	26.59	15.06	24.76	25.07	13.76

I processed the values in table 6 in order to find the relative strength of the fundamental and SF peaks for each student. To do this I subtracted the SPL of the peak in question from the SPL of the first formant peak, similar to the operations I performed for table 4 (see page 31). Using these new figures, I compared the relative strengths of the fundamental and the SF for each mode. To make the comparison, I calculated the difference between the relative strengths of the formant peaks between the two modes. I thus ascribed a number to the amount of change of those relative strengths. This number gives us a quantitative value for the amount of change in the resonance profile each singer makes for the mode in which they are singing. Finally, I averaged together the relative strengths and their differences for each Grade-Achievement Level Group, so that Group trends could be noted. The results can be found in table 7. The reader is reminded that the relative strength of a formant peak possesses an inverse relationship to the value of the number given. Therefore, the lower the value given on the chart, the greater is its relative strength. The values given in table 7, reflecting the relative strengths of the fundamental and the SF, confirm the findings of Rossing, Sundberg, and Ternström. The singers from Group 1 have a primary peak at the fundamental, which on average surpasses the first formant in strength (shown by the negative numbers given). Group 1's SF is quite weak,

Table 7 – Average Relative Strength of Fundamental and Singer's Formant Peaks

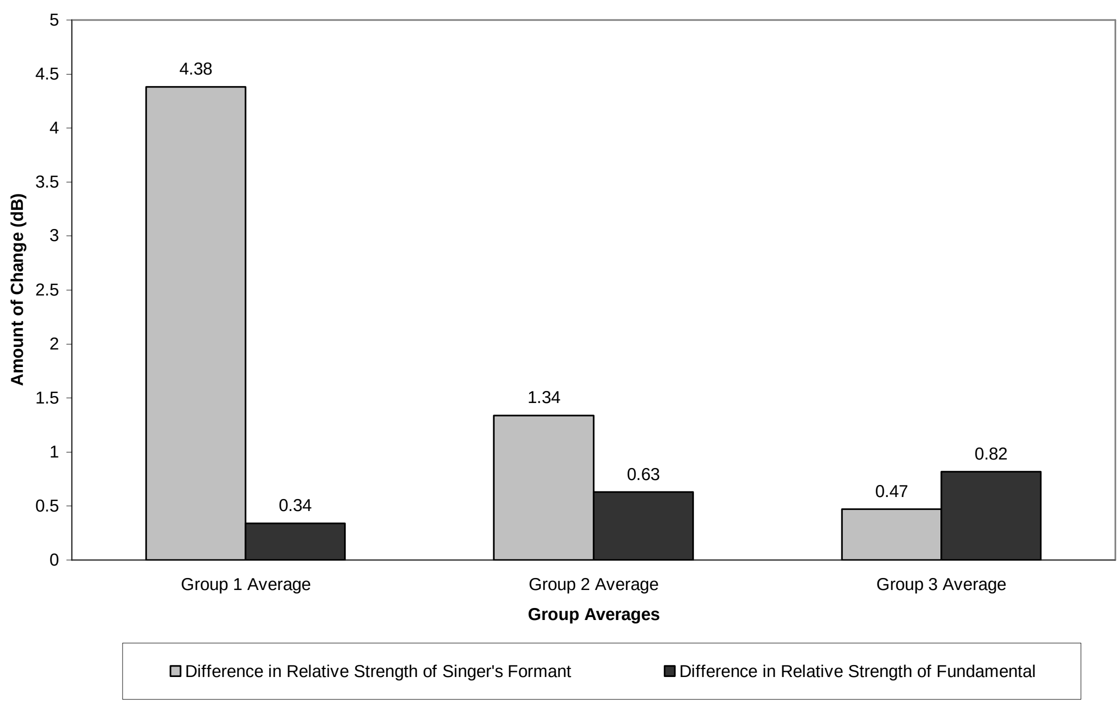
Participant	*Relative Strength of Fundamental Peak (L_{500} - L_{200})*			*Relative Strength of Singer's Formant Peak (L_{500} - L_{sf})*		
	Choral	*Solo*	*Difference*	*Choral*	*Solo*	*Difference*
101	-2.88	-3.26	0.38	13.06	3.99	9.07
102	0.38	-0.33	0.71	18.11	15.27	2.84
103	-2.97	-2.91	-0.06	15.33	14.10	1.23
Group 1 Avg.	**-1.83**	**-2.17**	**0.34**	**15.50**	**11.12**	**4.38**
201	2.10	0.94	1.16	13.15	9.42	3.73
202	0.90	1.01	-0.11	10.85	10.97	-0.12
203	-0.85	-1.69	0.84	11.14	10.73	0.41
Group 2 Avg.	**0.72**	**0.09**	**0.63**	**11.72**	**10.38**	**1.34**
301	0.72	0.22	0.50	8.88	7.86	1.02
302	-0.33	-1.71	1.38	8.62	8.45	0.17
303	0.87	0.31	0.56	11.53	11.31	0.22
Group 3 Avg.	**0.42**	**-0.40**	**0.82**	**9.68**	**9.21**	**0.47**

as reflected by the very high numbers. By contrast, Group 3 has a very strong fundamental and SF, while Group 2 lies comfortably between the other two.

The surprising discovery from this table is the *amount* of difference between the two modes displayed by each group. The singers in Group 1 show a large fluctuation in the relative strength of their SF between the two modes, while the range of relative strength of the fundamental is fairly small. For the singers in Group 3, the range of relative strength of the fundamental is larger, but the levels of the relative strength of the SF remain more consistent. The values for Group 2 average out to be between those of Groups 1 and 3. Upon closer examination of the statistics for each individual, however, major differences between the individuals become clear. The following chart shows the differences between the Grade-Achievement Level Groups in a much clearer fashion.

Figure 5 clearly reveals two trends distinguishing the grade-achievement level groups. First, as the age and experience of a singer increases, the amount of fluctuation in the relative strength of their SF dramatically decreases. Further, the greater the age and experience a singer has, the more change he effects in the relative strength of his fundamental frequency.

Figure 6 – Change in Relative Peak Strength in Choral and Solo Modes



PARTICIPANT SURVEY

Prior to the creation of the recordings that make up the bulk of the material for this study, each participant was surveyed about his attitudes surrounding singing. In particular, the survey questioned the participants' feelings regarding the differences between singing in the solo and choral modes. The survey was structured as a series of statements. The participants were asked to rate, on a scale of one to five, how much they agreed or disagreed with the statement in relation to themselves. A "one" signified that they disagreed strongly; a "three" meant that the participant was neutral; and a "five" was a sign of total agreement. The complete results of this survey can be found in the appendix (see page 50); however, some of the opinions and attitudes of the participants are worthy of mention here.

One significant difference between the three Grade Achievement level groups related to how the participants intend to pursue music in their lives after graduation. None of the participants from Group 1 (underclassmen) were certain they intended to pursue professional classical singing for their livelihood. In contrast, a majority of Group 2 and all of Group 3 said they agreed with the idea. This is one of the main features distinguishing Group 1 from the other two—the former have not yet made a decision to commit themselves to a career as professional soloists. Because of this difference in attitude, it is not necessarily in the best interests of the students in Group 1 to dedicate the number of hours required to pursue solo vocal technique and thereby learn to maximize the resonance in their SF.

A majority of the participants agreed with the ideas that there is a difference in techniques between choral and solo singing and that they should change their voice technique accordingly. Most believed that they could sing in both modes in a vocally healthy manner; however, a majority found singing in the solo mode to be easier than singing in the choral mode—especially those students in Groups 2 and 3. Again, this preference for solo singing may be due to the fact that their intention is to become professional soloists and are, therefore, concentrating on developing their voice for the solo mode.

A majority of participants marked “Neutral” when asked if they would prefer their choral directors to allow them to sing in a more soloistic manner, though none were against it. Further, the survey produced a similar number of “Neutral” responses when the participants were asked if they would like their voice teacher to help them with vocal techniques for choral singing, though most were not opposed to the idea.

All of the participants identified themselves as “baritones” or “bass-baritones” for the purposes of singing solo music, and all were comfortable with that classification. When asked what voice part they sing in choir, most of our participants again responded with either “Bass I” or “Bass II.” Two of the members of Group 1 (underclassmen) said that they were singing the tenor part in choir, though none said that they were uncomfortable with the assignment.

Finally, the participants were asked briefly to describe the characteristics of a good solo singing sound, and a good choral singing sound. Good solo sounds were often characterized with words such as “bright,” “forward,” “focused,” and “ring.” Descriptions of good choral sounds used words such as “blending,” “matching,” “dampered,” and “controlled vibrato.”

Chapter 5: Discussion

The primary findings for this study provide an understanding of the amount of fluctuation between choral and solo singing modes as indicated by the relative strengths of the singer's formant and the fundamental, and the effect that age and skill level of the singer determine these factors. The amount of change in the relative strength of a young singer's SF between the two modes is significant. The young singer has not learned the vocal control required for a consistent SF of substantial amplitude. He is willing and able to mold his voice to produce any number of timbres in order to achieve a musical goal insofar as he is able, such as soloistic "cut" or choral blend. The production of these sounds may not be the most vocally efficient for the individual singer; but vocal efficiency may not impact the choral performance, since many individuals are singing the same part. In a choral setting, the burden of generating sufficient volume and resonance is shared by the group so that no one individual is overly taxed. As I have outlined in Table 1 (p. 11), the fundamental frequency peak and F1 are of primary importance to most choral experiences.}

As the singer gets older, the overall strength of the SF increases, due primarily to his training as a soloist. The singer learns to control the resonance of his voice in order to make the most effective sound possible with the least amount of vocal effort in either solo or choral mode. It is for this reason that, as the older singer switches between the two modes, the strength of the SF in relation to the other formants remains more constant. The older singer is keenly aware that he must have a strong SF in order to sing in the most efficient way possible, and very rarely diminishes it.

The different effects of solo and choral vocal techniques on the SF for baritone and bass singers may become an area of discussion. Choral vocal technique relies on the quantity of singers to generate sufficient volume and resonance to carry into a hall and over accompanying instruments. Solo technique relies on the ability of the individual singer's resonance to produce sound in frequencies that the surrounding instruments or singers are not emphasizing in order to "cut through" to the audience.

The results of this study indicate that the time period when the singer learns to control the SF typically occurs during his junior and senior years as an undergraduate. Underclassmen have not yet developed the vocal control or the musculature to maintain a consistent SF, nor, according to the survey, has it been in their self-interest to do so. Graduate student singers are generally able to produce a singer's formant without fail; and by the end of the graduate student's education, they will be ready to enter the professional singing world. It is during the second half of an undergraduate career that many young baritones are learning to create the SF.

This learning process and subsequent volatility can be seen most clearly in the statistics shown for Group 2 in Tables 6 and 7 (found on pages 40 and 41). Participant 201 is singing at comparable decibel levels to those in Group 3; and though the relative strength of his fundamental peak is fluctuating well, the amount of change in the relative strength of his SF is still high. This instability indicates that the subject has not learned to control his SF resonance well. Participant 202 is generating an enormous amount of energy, but it is not under very much control. The relative strength of both his fundamental and SF peaks are stronger in the solo mode than in the choral mode. His trends suggest a general weakness of the first and second formants in his technique, and a preoccupation with power, especially when singing in the solo mode. Finally, participant 203 shows considerable control over the change in relative strength of his fundamental peak between solo and choral modes; and a steady, consistent singer's formant between the two modes as well. He simply needs to increase the relative strength of his SF to be comparable to the singers in Group 3. All three participants in Group 2 have pieces of the resonance puzzle, but they have not quite put them all together.

It is exactly at this time, when the voice performance major becomes an upperclassman that he starts seriously to consider a solo voice career. For those who embark on a solo career path, it is in their best interest to learn how to use their singer's formant well, since it is the primary method by which a singer is heard over an orchestra and acquires his unique timbral signature. For this skill the upperclassmen naturally turn to their voice teachers for guidance, and then make as part of their practice exercises that encourage those techniques required for a consistent SF.

Unfortunately, in their rush to learn how to sing in the solo mode most effectively, the upperclassmen may forget or neglect the techniques of ensemble singing. This oversight, when it occurs, happens chiefly because the singer is either not interested or not encouraged to maintain a healthy choral technique. Yet there are many situations in which aspiring classical solo vocal artists need to be able to sing within an ensemble, and they may find a healthy choral technique useful in such a case. Opera choruses, paying church choirs, and solo ensemble singing are just a few examples of such possible scenarios.

One must also be aware that the difference between the techniques of solo and choral singing do not begin and end with the singer's formant. The presence or absence of vibrato between the two modes is a debate that rivals—and possibly eclipses—the one over singer's formant resonance. Differences in enunciation and vowel modification are only a few of the many issues that would be helped by carefully considered research. Moreover, the challenges that face baritones and basses in switching back and forth between solo and choral modes are relatively moderate when compared to the shifts being made by tenors and sopranos. Not only are tenors dealing with issues surrounding the singer's formant, but they are doing in a range that requires them constantly to change vocal register. Though sopranos do not use a singer's formant per se, they have plenty of challenges before them. Sopranos are often asked to sing very high in their range, very softly, and with a minimum of vibrato. It is extremely difficult to do this and not develop some sort of tension in the larynx. Further, this vocal tension, if continued for long periods of time, can lead to some vocal health problems. In light of these factors, one might be encouraged to investigate the differences between solo and choral technique in sopranos, mezzo-sopranos, and tenors. Carefully considered research surrounding these issues is desperately needed in order for voice teachers and choral conductors better to serve their students in helping them to develop healthy techniques for solo and choral singing.

Given its musical and educational benefits, it is clear that choral participation is a key element to the training of a classical singer. A well-rounded singer must know how choirs and vocal ensembles work, and how to sing within them in a healthy manner. Choral experience not only expands the student's knowledge of vocal repertoire, but creates a singer that is more adaptable to various singing environments, and ultimately makes the singer more marketable in the profession. Further, the musical, aural, and artistic skills required to sing within an ensemble not only make vocal students more adaptable and viable musicians, but also open singers to a broader range of vocal choices and forms of expression that ultimately serve to create better vocal artists.

It must be recognized, however, that a college singer who intends to graduate as a vocal performance major will often have a goal of becoming a professional soloist. School curricula and teaching must empower students to achieve this logical career goal. One tool to accomplish this is a consistent, healthy singing technique able to encompass both choral and solo singing modes. The task for teaching that unified technique falls equally on the shoulders of choral directors and voice teachers. Further, if a student is having difficulty making shifts in his or her singing mode, it falls to the voice teacher and the choral director jointly to arrive upon a solution that best serves the long-term interests of the student. It is only through communication and an understanding of the characteristics of each mode that choral directors and voice teachers will be able to fulfill their obligations to the students in a manner that causes as little confusion and misunderstanding as possible. It is my hope that this study has helped to clarify some of those issues in order that such a dialogue may be started and continued.

Appendix

Survey Results

Age:[21] Group 1 Avg. 18.67 years (18, 18, 20)
Group 2 Avg. 22.67 years (21, 27, 20)
Group 3 Avg. 30.33 years (22, 37, 32)
Total Avg. 23.89 years

Class: Group 1 – 2 Freshmen, 1 Sophomore
Group 2 – 3 Juniors
Group 3 – 2 Masters, 1 Doctorate

Years of Choral Experience (including church choir, school choir, etc.):
Group 1 Avg. 9.67 years (10, 9, 10)
Group 2 Avg. 11.33 years(10, 15, 9)
Group 3 Avg. 9.33 years (8, 10, 10)
Total Avg. 10.11 years

Years of Private Voice Lessons
Group 1 Avg. 4.67 years (7, 5, 2)
Group 2 Avg. 6.00 years (6, 5, 7)
Group 3 Avg. 8.00 years (6, 10, 8)
Total Avg. 6.22 years

Please rate how much you agree or disagree with the following statements:[22]

1. ***I am interested in becoming a professional classical singer.***

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #	1/1	1/1	1/1, 1/2	1/2	1/2, 3/3
Total	1	1	2	1	4

2. ***There is a significant difference between the techniques of solo and choral singing.***

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #		1/2	1/2, 1/3	2/1, 1/2, 1/3	1/1, 1/3
Total	0	1	2	4	2

[21] The average age and years of experience for each group is given here, along with the individual ages and year amounts in parenthesis.
[22] Each statement appears here as it appeared to the subjects. The results are given in "Number/Group #" format. For example, in reaction to the first statement there is a "1/1" under "Strongly Disagree." This means that one member of Group 1 strongly disagreed. One member of Group 2 and all members of Group 3 "Strongly Agreed" with the statement.

3. When I sing in choirs, my technique changes from my typical solo technique.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #		2/2	1/3	1/1, 1/2, 1/3	2/1, 1/3
Total	0	2	1	3	3

4. When I sing in a choir, I have to modify my sound to blend with the choir.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #			1/2	1/1, 2/2, 2/3	2/1, 1/3
Total	0	0	1	5	3

5. When I sing a solo, I have to modify my sound in order to be heard.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #		1/2, 1/3	1/2	1/1, 1/2, 2/3	2/1
Total	0	2	1	4	2

6. I can sing in a choir in a vocally healthy manner.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #			1/1, 1/3	1/1, 2/2, 2/3	1/1, 1/2
Total	0	0	2	5	2

7. I can sing a solo in a vocally healthy manner.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #				1/2, 1/3	3/1, 2/2, 2/3
Total	0	0	0	2	7

8. It is easier for me to sing in choir.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #	1/1, 1/2	1/2, 2/3	1/1, 1/3	1/1, 1/2	
Total	2	3	2	2	0

9. It is easier for me to sing as a soloist.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #	1/2	1/1, 1/2	1/3	1/1, 1/2, 2/3	1/1
Total	1	2	1	4	1

10. It would be helpful to me if my choir director allowed me to sing in a more soloistic way in my choir.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #			3/1, 1/2, 1/3	1/2, 2/3	1/2
Total	0	0	5	3	1

11. It would be helpful if my voice teacher would teach me good vocal technique for a choral setting.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #	1/2		3/1, 1/2, 1/3	1/2, 2/3	
Total	1	0	5	3	0

12. When I sing in a choir, my voice part is **[Tenor I, Tenor II, Bass I, Bass II],**

	Tenor I	Tenor II	Bass I	Bass II
Number/ Group #	1/1	1/1	1/1, 1/2, 3/3	2/2
Total	1	1	5	2

and I am comfortable with that assignment.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #			1/3	2/1, 2/2, 1/3	1/1, 1/2, 1/3
Total	0	0	1	5	3

13. *When I sing as a soloist, my voice classification is* [Tenor, Baritone, Bass-Baritone, Bass],

	Tenor	Baritone	Bass-Baritone	Bass
Number/ Group #		2/1, 2/2, 3/3	1/1, 1/2	
Total	0	7	2	0

and I am comfortable with that classification.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number/ Group #				1/1, 1/2, 2/3	2/1, 2/2, 1/3
Total	0	0	0	4	5

14. Please briefly describe the characteristics of your best solo singing sound.

Group 1

- A sound that is full and resonant with clear diction and dynamic control
- Loud enough to be heard without any physical straining: a healthy sound
- It's got an interesting sound, and it's very flexible. I can sing in all sorts of genres, classical, pop, jazz, ethnic, etc. Also, I have good resonance.

Group 2

- I sound best with a nice Forward tone. My tone sounds best with an approach that every vowel sound has an "Ah" sound to it.
- bright sound with some point and focus, well supported and deep enough in my body to efficiently support it with the breath.
- large dynamic range, healthy vibrato, more ringing, rich

Group 3

- Bright and round. plus good timbre
- Rich, strong, healthy
- Ringy, forward, Released, Even, Full of breath support, loose unaltered laryngeal position, high palette

15. Please briefly describe the characteristics of your best choral singing sound.

Group 1

- a sound that is full and blends well with diction and dynamics relative to the other singers
- rich, something that doesn't stick out, sometimes controlled vibrato
- It blends well, and it is sort of 'dampered' or that is, it is a lot quieter

Group 2

- I use a Forward tone with rounder lips. I listen to everyone around me to make sure I am matching.
- I think on choral singing to be the same as solo singing the only difference for me would be modifying vowels to find a unification between all the choir.
- Somewhat smaller dynamic range, less vibrato, more blended, fairly rich

Group 3

- Bright and beautiful plus light
- Mellow, well blended
- Even, warm, breath support ample efficient singing

Glossary

acoustic spectrum. The distribution of energy as a function of frequency in a given sound. A spectrum is generally shown as a graph with the x-axis representing frequency measured in hertz (Hz), and the y-axis showing energy measured in decibels (dB). Also known as *sound spectrum*.

audio filter. Something that magnifies certian frequencies of a complex sound, and significantly weakens others. In the case of the human voice, the audio filter is the vocal tract beginning at the vocal folds and ending at the lips.

binaural recording. A recording technique used to accurately reproduce the effect of hearing a sound in space, allowing the listener to hear a recorded sound's location (behind, ahead, above, etc.) in relation to the microphone during the recording.

choral effect. A phenomenon in which the listener's ear perceives multiple sound sources coming from the same spatial and temporal location as one sound source.

complex sound. A sound that contains more than one frequency.

decibel (dB). A logarithmic unit of measurement used for sound pressure level. Its logarithmic nature allows very large or very small ratios to be represented by a convenient number. An increase of 3 dB corresponds to an approximate doubling of power.

energy. see Sound Pressure Level.

formant. A decibel level increase (or peak) of a band of frequencies within the acoustic spectrum of a complex sound. The peak is caused by the enhancement of a frequency band within the sound by an acoustic filter.

frequency. The measurement of the number of cycles per second the waveform completes. Frequency is often heard as pitch, and is measured in hertz (Hz). For example, the frequency of A above middle C is 440 Hz.

frequency band. A range of frequencies. The term is most often used to identify particular portions of the audio spectrum.

fundamental (frequency). The lowest frequency in a harmonic series or complex sound. It is often heard as the pitch of the sound.

hertz (Hz). A measure of wave frequency. It is also known as cycles per second.

intensity. see Sound Pressure Level.

International Phonetic Alphabet (IPA). A system of phonetic notation devised as a standardized representation of the sounds of spoken language. This system is used by linguists, speech therapists, and language teachers as well as singers and other language professionals.

inverse filtering. A computerized process by which the effects of an audio filter upon a complex sound are eliminated. What remains is the sound source spectrum.

kilohertz (kHz). One thousand hertz.

Lombard vocal response. A phenomenon that occurs when any person is unable to hear themselves speak through masking due to noise or reduced auditory function, and results in that person increasing his volume in order that he hear himself sufficiently.

Long-Term Average Spectrogram (LTAS). A line graph tracing the average intensity of all frequency bands of a complex sound over the course of the sample. The graph shows the sound pressure level on the y-axis and the frequency level on the x-axis.

oscillograph. An instrument for indicating and recording time-varying electrical quantities, such as current and voltage. Before the use of spectrograms, ocillographs were used by scientists to graph sound waves by connecting them to microphones. The microphone would convert the sound waves into an electrical current which was then measured.

overtone. see partial.

partial. A waveform that is generated as a sympathetic vibration to a wave at a lower frequency, called the fundamental. A partial can be either harmonic or inharmonic. A harmonic partial is one at an integer multiple of the fundamental frequency, and will follow the "overtone series." An inharmonic partial is one at a non-integer multiple of a fundamental frequency.

relative strength. A measurement showing the difference between the SPL of a given formant peak and that of the first formant peak, which is often the peak with the most energy. The formula is [$F_1 - F_x$]; where F_1 is the SPL of the first formant, and F_x is the strength of the formant in question. The numerical value given is in inverse relation to the strength of the peak in question. In other words, the lower the number given, the greater the relative strength of the peak.

Self-to-Other Ratio (SOR). Term developed by Sten Ternström meaning the ratio of the decibel level heard by a chorister over the decibel level at which he sings.

Singer's Formant (SF). An area of higher acoustical energy between 2300 and 3200 Hz in the resonance of a singer's voice, caused by the clustering of singing formants

3, 4 and 5. It is a primary characteristic in the timbre of Western classical singing.

Sound Pressure Level (SPL). The sound pressure level is a measure of the amount of pressure change in a medium generated by a wave. A change in sound pressure level is often heard as a change in the intensity or volume of a sound. It is measured in decibels (dB).

sound source. An object that is set into vibration thereby creating a sound wave. In the case of singing, it is the vocal folds.

sound source spectrum. The audio spectrum generated by the sound source. In the case of singing, it is the audio spectrum generated by the vocal folds.

spectrogram. A graphic representation of the audio spectrum of a sound sample. Shown in graph form in which the x-axis represents time, the y-axis represents frequency, and the shade of gray printed within the graph reflects the intensity of the sound.

vocal tract. The part of the body that acts as the sound filter for the voice. It consists of the laryngeal cavity, the pharynx, the oral cavity, and the nasal cavity.

voice category. A system of classifying voices based on timbre, frequency range, tessitura, gender and other factors. Examples of voice categories are soprano, mezzo-soprano, contralto, tenor, baritone, and bass.

Voice Range Profile (VRP). A graphic representation of the potential dynamic range of a voice on each discrete pitch the voice is able to sing. VRPs are used most often in voice therapy as a tool for diagnosis and tracking progress in patients, though recently applications for using VRP have been developed to help singers.

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Vita

Brian B. Carter was born in Honolulu, Hawaii on April 2, 1970 to Frederick B. and Beverly B. Carter. His family soon moved to Palo Alto, California where he grew up participating in school choirs and dramatic productions at the Palo Alto Children's Theater. He graduated from Palo Alto High School in June 1988, and attended college at The College of Wooster, Foothill College, De Anza College, and finally San José State University where he received a Bachelor's of Music degree in 1997. While attending San José State, he found a love of performing opera as the perfect marriage between classical singing and drama. He became a Principal Resident Artist at Opera San José where he performed fifteen principal and supporting roles. He went on to study at The University of Texas where he received a Masters of Music in 2004 and a Doctorate of Musical Arts in 2007. He began to teach voice in 2005 when he was awarded a teaching assistantship at the University of Texas, and has gone on to teach privately at Anderson High School in Austin, Texas and in the Austin community. He maintains employment as a choir section leader at University United Methodist Church of Austin under the direction of Marc Erck, and continues to perform with companies such as Austin Lyric Opera, Des Moines Metro Opera, Opera Illinois, Opera in the Heights, and Sarasota Opera.

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